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4.4-5.0 GHz MICROWAVE LINKS IN TEHRAN, IRAN

FIELD MEASUREMENT REPORT

BY

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July 1977

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US ARMY COMMUNICATIONS-ELECTRONICS
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Tehran Assistance Plan (TAP)	AN/FRC-157(V)
Microwave	
Electromagnetic Compatibility (EMC)	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Results are provided on path loss measurements and analyses to evaluate the feasibility and expected performance of four proposed 4.4-5.0 GHz microwave links in Tehran, Iran. Specific design recommendations on each link are included. Results are provided on spectrum occupancy measurements and analyses at each site and a frequency plan is provided to increase the probability of the proposed microwave links being electromagnetically compatible with the environment.

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ABSTRACT

The results of path loss and spectrum occupancy measurements and analyses are provided which evaluate four prospective 4.4-5.0 GHz microwave communication links in Tehran, Iran. These links are a part of the Tehran Assistance Plan (TAP), a communication plan to upgrade and modernize communications in Tehran. The four links are: Embassy to Receiver Site, Technical Control to Receiver Site, Mac Terminal to Technical Control, and Mac Terminal to Receiver Site.

Based upon the path loss measurements and analyses, specific recommendations are included for each link to include transmitter power, antenna size and antenna height above ground. Radio propagation predictions are included to show the expected reliability of each link.

The spectrum occupancy measurements and analyses identify the regions of potential interference and a frequency plan is included.

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1.0 INTRODUCTION

1.1 ASSIGNMENT OF THE TASK. In August 1976, this Agency was tasked, by the US Army Communications Command (references 1 and 2), to perform various functions in support of the Tehran Assistance Plan (TAP). This tasking was further delineated in March 1977 by the US Army Communications Systems Agency (references 2 and 3). TAP is a communications plan to upgrade and modernize the existing communications in the greater Tehran city area. In fulfillment of portions of the tasking, this Agency performed on-site path loss and spectrum occupancy measurements over four prospective 4.4-5.0 GHz microwave links: Embassy to Receiver Site, Technical Control to Receiver Site, Mac Terminal to Technical Control, and Mac Terminal to Receiver Site.

1.2 BACKGROUND. The Embassy to Receiver Site was an existing 8 GHz link using AN/FRC-80 radios, the Technical Control to Receiver Site was an existing 4 GHz link using AN/GRC-66 radios, and the Mac Terminal to Technical Control was an existing 200-400 MHz link using AN/TRC-24 radios. All three of the links were to be upgraded and modernized using one watt frequency diversity, AN/FRC-155(V), or 5 watt frequency diversity, AN/FRC-157(V), radios which operate in the 4.4-5.0 GHz frequency band. The Mac Terminal to Receiver Site was not an existing link but was included in the study as a possible alternate route to the Mac Terminal. Figure 1 shows the layout of the four links. Table 1 shows the equipment characteristics. The RF portion of the links (baseband-to-baseband) will be capable of handling traffic data rates up to 12.6 MB/s.

1.3 REASON FOR MEASUREMENTS.

1.3.1 Path Loss Measurements. There is and has been a considerable amount of construction of buildings in Tehran and it was suspected that some of the links were obstructed by this man-made terrain clutter. Accurate path profiles showing this terrain clutter were not available. Furthermore, there is a considerable smog problem in Tehran mostly caused by automobiles and the rising dust from the construction. The effects of this dense smog on microwave links cannot be accurately predicted. Therefore, on-site measurements were required to determine the path loss, required antenna sizes and heights above ground, and the expected microwave link performance.

1.3.2 Spectrum Occupancy Measurements. The data base of the Electromagnetic Compatibility Analysis Center (ECAC) showed only two 4.4 to 5.0 GHz signals for the Tehran area. Therefore, to increase the confidence level of the frequency plan and the electromagnetic compatibility of the proposed microwave links with the environment, spectrum occupancy measurements were taken at each site.

1.4 DCA QUALITY. The radios being proposed for the TAP microwave links are analog radios modified for three-level partial response (quasi-digital radios). Current DCA standards do not clearly specify a reliability and bit-error-rate (BER) objective for the RF portion (baseband-to-baseband) of digital and quasi-digital microwave links. However, in communication

systems such as the Digital European Backbone, Stage I, DCA has been specifying a BER of 5×10^{-9} for 99.999% of a year (reference 5) as the design objective. Therefore, throughout this report DCA quality shall be taken as a BER of 5×10^{-9} for a 99.999% availability.

2.0 APPROACH TO THE TASK

2.1 GENERAL OBJECTIVES. The general objectives of the study were to measure path loss over each link and perform spectrum occupancy measurements at each site. From the path loss measurements, the required antenna sizes, antenna heights above ground (using existing towers), and expected microwave link performance were determined. From the spectrum occupancy measurements, the regions of potential interference were identified and the frequency plan was developed.

2.2 GENERAL REQUIREMENTS.

2.2.1 Personnel. A measurements team from the Electromagnetics Engineering Office (EMEO), of this Agency, was required to conduct the field measurements, analyze the data and prepare the technical report.

2.2.2 Equipment. A frequency oscillator, power amplifier, antennas, low noise pre-amplifiers, field intensity meter, spectrum analyzer, strip chart recorder and ancillary equipment were required to conduct the measurements (see Appendices A and C for detailed equipment lists and diagrams).

2.2.3 External Support. USACC-IRAN provided on-site support, transportation, and use of their facilities at each location. They also assisted in providing two-way communication over each link during the antenna alignment phase of the field measurements. The US Air Force and US Embassy also provided the use of their facilities.

2.3 SCHEDULE. The on-site path loss and spectrum occupancy measurements were performed during the period of 10 May - 12 Jun 77.

3.0 SUMMARY OF RESULTS

3.1 PATH LOSS MEASUREMENTS. The results of the path loss measurements and analyses are provided in this section. The details of the measurement equipment, procedure, data reduction and analyses techniques are provided in Appendix A.

3.1.1 Embassy to Receiver Site Link. Table 2 and Figure 2 show the measured path loss, relative to free space, over the Embassy to Receiver Site link. The transmit antenna was located near the top of the Receiver Site tower at 40.5 feet. The receive antenna, at the Embassy, was varied in height from 38.8 to 95.0 feet. In reference 6, previous measurements had been taken over this link at 7.8 GHz and it was expected that the path would be obstructed and subject to multipath ground reflection problems at 4.4-5.0 GHz. However, as Table 2 and Figure 2 show, the path was unobstructed (free space

path loss conditions) utilizing the top of the existing towers and no multipath ground reflections, which add to or cancel the desired signal, were observed. Because of the ground reflection problems observed in reference 6, measurements with both horizontal and vertical porarization were taken. However, the difference observed between the two polarities is not considered significant.

It is recommended that the link be installed with a 4 foot dish at the 92 foot level at the Embassy and a 6 foot dish at the 50 foot level at the Receiver Site. The radios recommended are the one watt frequency diversity AN/FRC-155(V) radios. Table 3 shows that the predicted reliability (time availability) exceeds DCA quality. It is highly probable that the link will become obstructed in the future because of the great amount of high rise construction going on continually in downtown Tehran. The recommendations provided herein include a 13 dB safety margin. Thus, the link can still provide DCA quality if the obstruction losses should increase from 0 dB (as measured) up to 13 dB.

3.1.2 Technical Control to Receiver Site Link. Table 4 and Figure 3 show the measured path loss, relative to free space, over the Technical Control to Receiver Site link. The transmit antenna was located near the top of the Receiver Site tower at 40.5 feet. The receive antenna, at the Technical Control, was varied in height from 31.0 to 111.0 feet. Free space path loss was obtained using the upper portions of the existing towers.

It is recommended that the link be installed with a 4 foot dish at the 100 foot level at the Technical Control and a 4 foot dish at the 43 foot level at the Receiver Site. The one watt frequency diversity, AN/FRC-155(V), radios are recommended. Table 5 shows that the link is predicted to provide DCA quality. A 19 dB safety margin is included in the recommended design.

3.1.3 Mac Terminal to Technical Control Link. Table 6 and Figure 4 show the measured path loss over the Mac Terminal to Technical Control link. The transmit antenna was located near the top of the Technical Control tower at 103.3 feet. The receive antenna, at the Mac Terminal was varied in height from 29.7 to 83.0 feet. The link was found to be badly obstructed and as antenna height was increased, peaks and nulls in the measured path loss were observed which were probably caused by ground reflections adding to or subtracting from the desired signal. Furthermore, the amount of short term, rapid fading was observed to be less near the top of the Mac Terminal tower. Therefore, best performance can be obtained by mounting antennas near the tops of the existing towers even though equally strong signals can be obtained at lower heights. Table 7 shows that 5 watt frequency diversity radios with 12 foot antennas at each end of the link are required for DCA quality with no safety margin. Since the Mac Terminal to Receiver Site link was determined to be a more cost effective route to the Mac Terminal, this link is not recommended.

3.1.4 Mac Terminal to Receiver Site Link. Table 8 and Figure 5 show the measured path loss over the Mac Terminal to Receiver Site Link. The transmit antenna was located near the top of the Receiver Site tower at 40.5 feet.

The receive antenna, at the Mac Terminal, was varied in height from 39.3 to 83.0 feet. The link was observed to be a diffraction link with obstruction losses running from 19.9 to 28.4 dB. As in the case of the other link to the Mac Terminal, peaks and nulls together with a reduction in short term, rapid fading were observed as the antenna height at the Mac Terminal was increased. Figure 6 shows a comparison of the two routes into the Mac Terminal. The link from the Mac Terminal to the Receiver Site is the more cost effective of the two routes and is therefore recommended. The recommended antenna heights, using the existing towers, are 75 feet at the Mac Terminal and 35 feet at the Receiver Site.

At the time of the writing of this report, it had not been determined if the route to the Mac Terminal requires DCA quality or what antenna sizes can be supported on the existing towers. Therefore, Table 9 shows the predicted performance of several sets of equipment over this link. Two 8 foot dishes, a 6 and a 10 foot dish, or a 4 and a 15 foot dish are predicted to provide DCA quality using the 5 watt, AN/FRC-157(V) radios. If less than DCA quality is acceptable over this link, Table 9 also shows the predicted performance of other equipment configurations using the 1 and 5 watt radios.

3.2 SPECTRUM OCCUPANCY MEASUREMENTS. Spectrum occupancy measurements were taken at the Embassy, Receiver Site, Technical Control and the Mac Terminal. A total of 6, 17, 15, and 16 signals, respectively, were observed. The details of the measurement equipment, procedure, data reduction and analyses techniques are provided in Appendix C. The results of the measurements and analyses are shown in Tables 10-13. The regions of potential interference are to be avoided in selecting receive frequencies at each site.

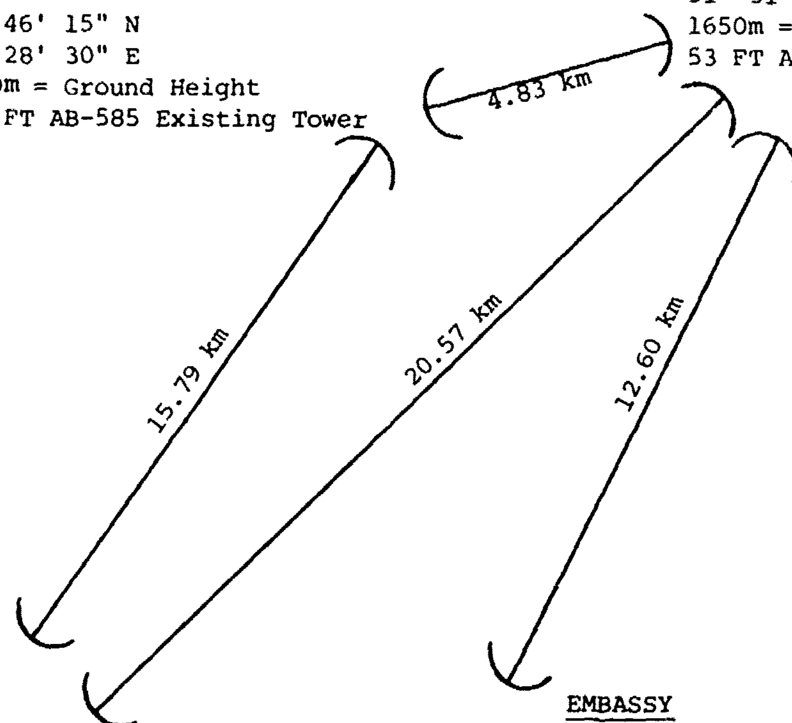
4.0 CONCLUSIONS Tables 14 and 15 constitute the conclusions of this report. Table 14 summarizes the recommended design of each link, based upon the measured path losses and analyses of the path losses. The spectrum occupancy measurements were provied to ECAC who, in turn, provided the recommended frequency plan shown in Table 15.

FIGURE 1

LAYOUT OF THE 4.4-5.0 GHz MICROWAVE LINKS

RECEIVER SITE
35° 47' 20" N
51° 31' 25" E
1650m = Ground Height
53 FT AB-585 Existing Tower

TECHNICAL CONTROL
35° 46' 15" N
51° 28' 30" E
1439m = Ground Height
108 FT AB-585 Existing Tower



MAC TERMINAL
35° 41' 25" N
51° 19' 52" E
1208 m = Ground Height
82 FT Existing Flood Light Tower

EMBASSY
35° 42' 36" N
51° 25' 24.5" E
1210 m = Ground Height
94 FT AB-105 Existing Tower

TABLE 1

EQUIPMENT CHARACTERISTICS

1. Radio nomenclature:

   a. 1 Watt Frequency Diversity AN/FRC-155(V) radios, or

   b. 5 Watt Frequency Diversity AN/FRC-157 (V) radios.

   c. These are analog radios to be modified for 3-level partial response.

2. 4.4-5.0 GHz = frequency range.

3. 12.6 MB/s = maximum traffic capability.

4. 8 dB = nominal receiver noise figure.

5. 25 MHz = receiver IF bandwidth (3 dB).

6. 50 MHz = receiver RF bandwidth (3 dB)

7. 110 FT = Transmission line length at Embassy.

8. 100 FT = Transmission line length at Receiver Site.

9. 150 FT = Transmission line length at Technical Control.

10. 200 FT = Transmission line length at Mac Terminal.

11. 1.25 dB/100 FT = Transmission line loss (appropriate isolator and circulator loss must be added).

12. -69.5 dBm = required signal level for a BER of 5×10^{-9}.

13. Parabolic antenna sizes as required.

14. Existing towers are to be utilized.

TABLE 2

EMBASSY TO RECEIVER SITE - MEASURED PATH LOSS

4720 MHz

ANTENNA HEIGHT		VERTICAL POLARITY			HORIZONTAL POLARITY		
RECEIVER SITE FT	EMBASSY FT	TOTAL PATH LOSS dB	FREE SPACE LOSS dB	OBSTRUCTION LOSS dB	TOTAL PATH LOSS dB	FREE SPACE LOSS dB	OBSTRUCTION LOSS dB
40.5	38.8	146.6	127.9	18.7	144.6	127.9	16.7
40.5	48.8	132.6	127.9	4.7	136.6	127.9	8.7
40.5	58.5	129.1	127.9	1.2	131.6	127.9	3.7
40.5	68.5	127.8	127.9	-0.1	131.1	127.9	3.2
40.5	95.0	127.1	127.9	-0.8	127.1	127.9	-0.8

FIGURE 2

EMBASSY TO RECEIVER SITE - MEASURED PATH LOSS

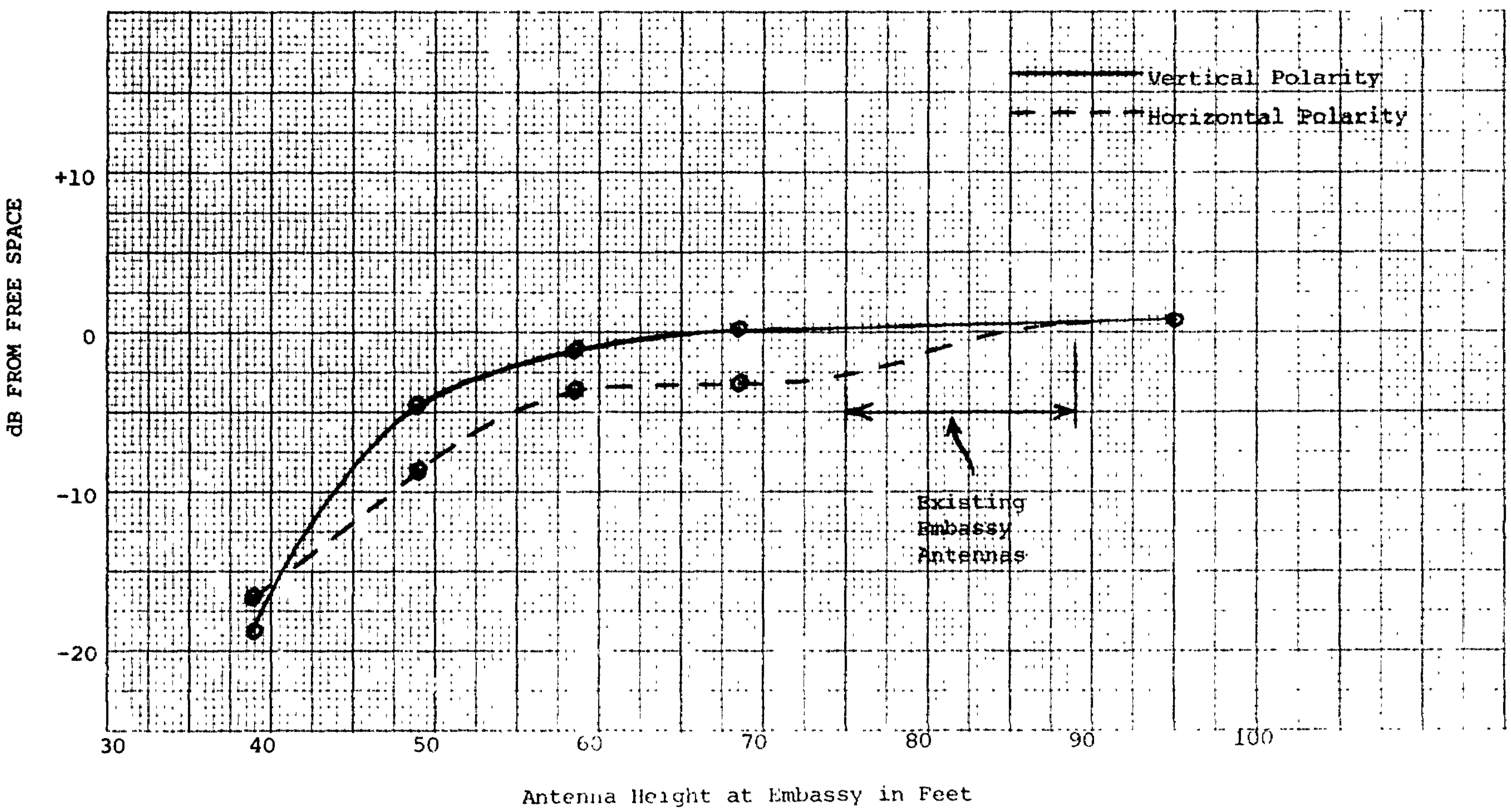


TABLE 3

EMBASSY TO RECEIVER SITE
SUMMARY OF PREDICTED PERFORMANCE

PATH		EMB./RCVR
DISTANCE - KM		12.60
FREQUENCY - MHZ		4700.0
PROP. MECHANISM		LOS
CLIMATE TYPE		1
ORDER OF DIVERSITY		DUAL
XMTR POWER - WATTS		1
ANT HT ABV GND- M/M		28.0/15.2
XMTR ANT SIZE - FT		4
RCVR ANT SIZE - FT		6
NET ANTENNA GAIN-DB		68.65
FWD FEEDER LOSS -DB		4.68
RCVR NOISE FIG - DB		8.0
IF BANDWIDTH - MHZ		25.00
RCVR THRESHOLD- DBM		-69.50
FOR A BER OF		5.0E-09
99.99 PER- CENT	PATH LOSS -DB	131.19
	RCVD PWR -DBM	-37.22
99.90 PER- CENT	PATH LOSS -DB	130.62
	RCVD PWR -DBM	-36.66
99.0 PER- CENT	PATH LOSS -DB	129.95
	RCVD PWR -DBM	-35.98
95.0 PER- CENT	PATH LOSS -DB	129.32
	RCVD PWR -DBM	-35.36
90.0 PER- CENT	PATH LOSS -DB	129.00
	RCVD PWR -DBM	-35.03
50.0 PER- CENT	PATH LOSS -DB	127.85
	RCVD PWR -DBM	-33.89

TIME AVAILABILITY:

OBJECTIVE	99.9990
PREDICTED	100.00000

TABLE 4

TECHNICAL CONTROL TO RECEIVER SITE - MEASURED PATH LOSS

4700 MHz, HORIZONTAL POLARITY

ANTENNA HEIGHT		TOTAL	FREE	OBSTRUC-
RECEIVER SITE	TECHNICAL CONTROL	PATH LOSS	SPACE LOSS	TION LOSS
FT	FT	dB	dB	dB
40.5	31.0	125.7	119.6	6.1
40.5	58.5	122.4	119.6	2.8
40.5	85.0	119.6	119.6	0
40.5	111.0	120.4	119.6	0.8

FIGURE 3

TECHNICAL CONTROL TO RECEIVER SITE - MEASURED PATH LOSS

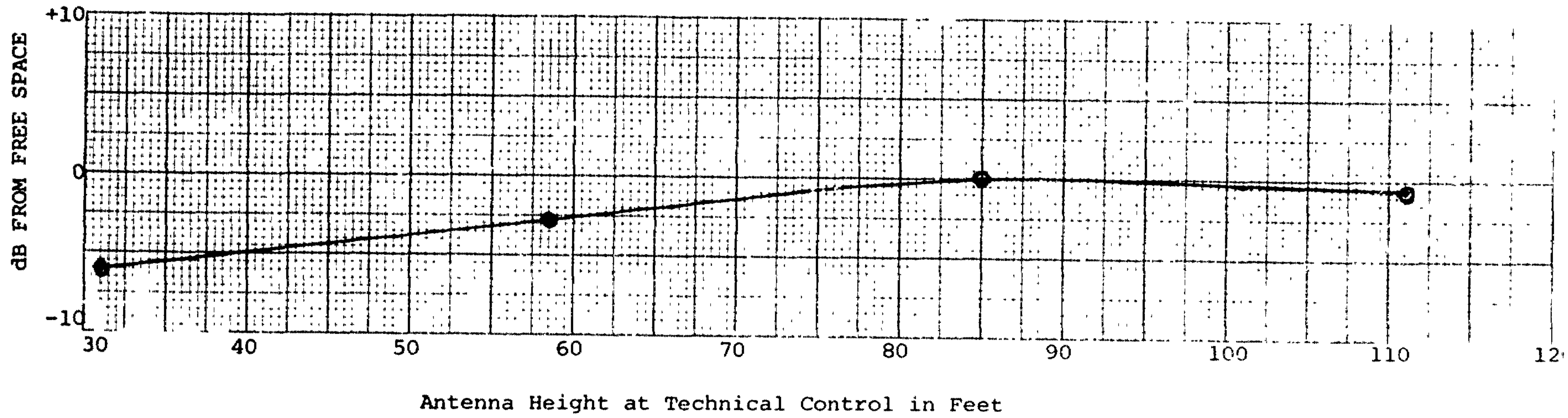


TABLE 5

TECHNICAL CONTROL TO RECEIVER SITE
SUMMARY OF PREDICTED PERFORMANCE

PATH	TECF/RCVR
DISTANCE - KM	4.63
FREQUENCY - MHZ	4700.0
PROP. MECHANISM	LOS
CLIMATE TYPE	1
ORDER OF DIVERSITY	DUAL
XMTR POWER - WATTS	1
ANT HT ABV GND- M/M	30.5/13.1
XMTR ANT SIZE - FT	4
RCVR ANT SIZE - FT	4
NET ANTENNA GAIN-DB	65.13
FWD FEEDER LOSS -DB	4.94
RCVR NOISE FIG - DB	8.0
IF BANDWIDTH - MHZ	25.00
RCVR THRESHOLD- DBM	-69.50
FOR A BER OF	5.0E-09

99.99 PER-CENT	PATH LOSS -DB	120.32
	RCVD PWR -DBM	-30.17
99.90 PER-CENT	PATH LOSS -DB	120.19
	RCVD PWR -DBM	-30.05
99.0 PER-CENT	PATH LOSS -DB	120.04
	RCVD PWR -DBM	-29.89
95.0 PER-CENT	PATH LOSS -DB	119.90
	RCVD PWR -DBM	-29.75
90.0 PER-CENT	PATH LOSS -DB	119.83
	RCVD PWR -DBM	-29.68
50.0 PER-CENT	PATH LOSS -DB	119.57
	RCVD PWR -DBM	-29.42

TIME AVAILABILITY:

OBJECTIVE	99.9990
PREDICTED	100.00000

TABLE 6

MAC TERMINAL TO TECHNICAL CONTROL - MEASURED PATH LOSS

4700 MHz, VERTICAL POLARITY

ANTENNA HEIGHT		TOTAL PATH LOSS	FREE SPACE LOSS	OBSTRUCTION LOSS
TECHNICAL CONTROL FT	MAC TERMINAL FT	dB	dB	dB
103.3	29.7 (1)	165.3	129.9	35.4
103.3	39.3 (2)	158.6	129.9	28.7
103.3	56.5 (2)	161.1	129.9	31.2
103.3	74.5 (2)	164.6	129.9	34.7
103.3	83.0 (2)	159.6	129.9	29.7

(1) Measurement Taken from the Roof of the Mac Terminal Building (17.7 feet above the 12 foot building).

(2) Measurement taken from a nearby 82 foot flood light tower.

FIGURE 4

MAC TERMINAL TO TECHNICAL CONTROL - MEASURED PATH LOSS

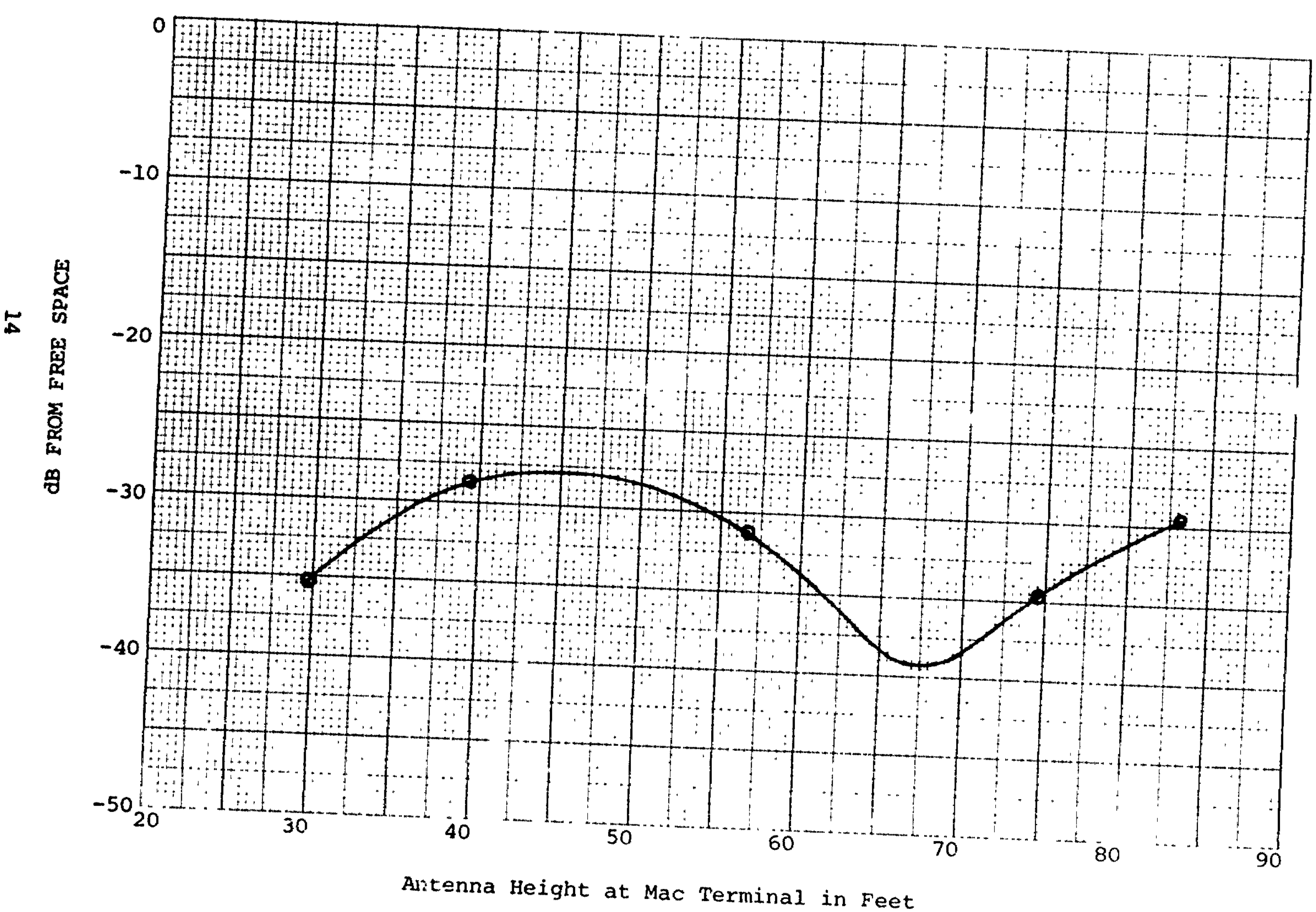


TABLE 7

MAC TERMINAL TO TECHNICAL CONTROL
SUMMARY OF PREDICTED PERFORMANCE

PATH	MAC./TECH
DISTANCE - KM	15.79
FREQUENCY - MHZ	4700.0
CLIMATE TYPE	1
ORDER OF DIVERSITY	DUAL
XMTR POWER - WATTS	5
ANT HT ABV GND- M/M	24.4/30.5
XMTR ANT SIZE - FT	12
RCVR ANT SIZE - FT	12
NET ANTENNA GAIN-DB	84.21
FWD FEEDER LOSS -DB	6.43
RCVR NOISE FIG - DB	6.0
IF BANDWIDTH - MHZ	25.00
RCVR THRESHOLD- DBM	-69.50
FOR A BER OF	5.0E-09

99.99 PER-CENT	PATH LOSS -DB	164.98
	RCVD PWR -DBM	-50.21
99.90 PER-CENT	PATH LOSS -DB	164.29
	RCVD PWR -DBM	-49.52
99.0 PER-CENT	PATH LOSS -DB	163.46
	RCVD PWR -DBM	-48.68
95.0 PER-CENT	PATH LOSS -DB	162.70
	RCVD PWR -DBM	-47.93
90.0 PER-CENT	PATH LOSS -DB	162.30
	RCVD PWR -DBM	-47.53
50.0 PER-CENT	PATH LOSS -DB	160.90
	RCVD PWR -DBM	-46.13

TIME AVAILABILITY:

OBJECTIVE	99.9990
PREDICTED	99.99935

TABLE 8

MAC TERMINAL TO RECEIVER SITE - MEASURED PATH LOSS

4700 MHz, VERTICAL POLARITY

ANTENNA HEIGHT		TOTAL PATH LOSS	FREE SPACE LOSS	OBSTRUCTION LOSS
RECEIVER SITE FT	MAC TERMINAL FT	dB	dB	dB
40.5	39.3	152.6	132.2	20.4
40.5	56.5	160.6	132.2	28.4
40.5	74.5	152.6	132.2	20.4
40.5	83.0	152.1	132.2	19.9

<u>FIGURE 5</u>

MAC TERMINAL TO RECEIVER SITE - MEASURED PATH LOSS

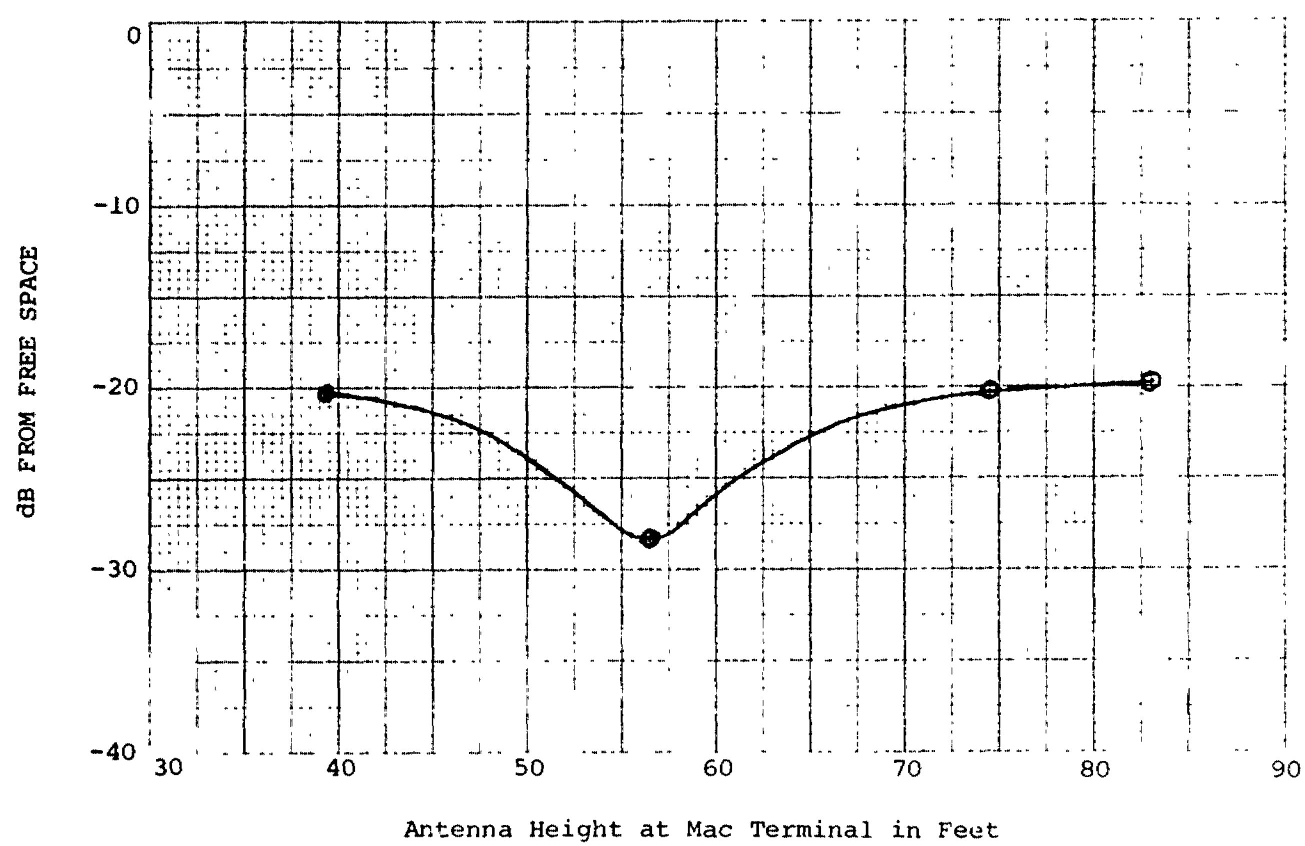


FIGURE 6

COMPARISON OF TWO LINKS - MEASURED PATH LOSS

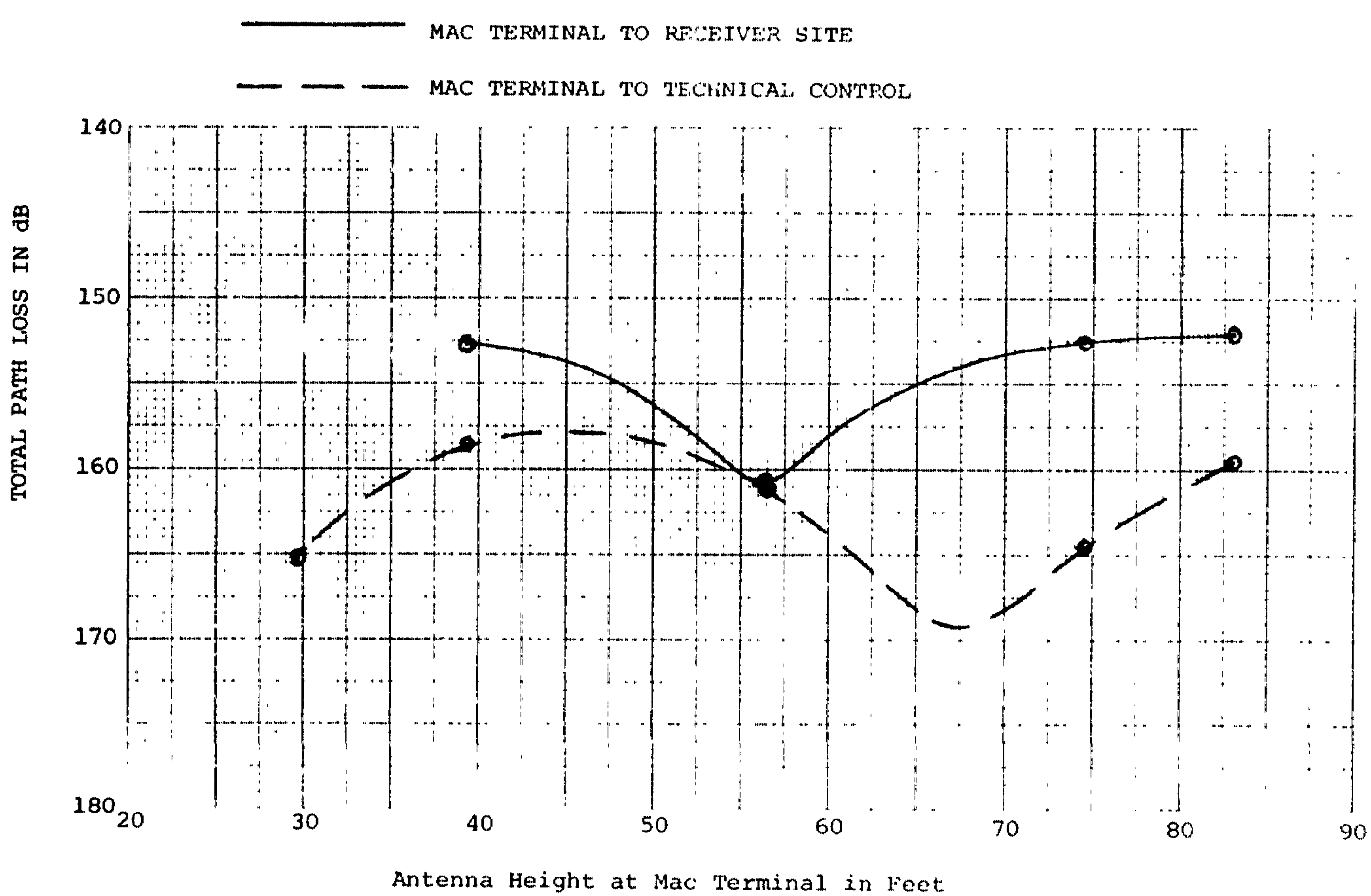


TABLE 9

MAC TERMINAL TO RECEIVER SITE
SUMMARY OF PREDICTED PERFORMANCE

PATH	MAC./RCVR	MAC./RCVR	MAC./RCVR	MAC./RCVR	MAC./RCVR	MAC./RCVR	MAC./RCVR	MAC./RCVR
DISTANCE - KM	20.57	20.57	20.57	20.57	20.57	20.57	20.57	20.57
FREQUENCY - MHZ	4700.0	4700.0	4700.0	4700.0	4700.0	4700.0	4700.0	4700.0
CLIMATE TYPE	1	1	1	1	1	1	1	1
ORDER OF DIVERSITY	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL	DUAL
XMTR POWER - WATTS	5	5	5	1	5	1	1	1
ANT HT ABV GND- M/M	22.9/10.7	22.9/10.7	22.9/10.7	22.9/10.7	22.9/10.7	22.9/10.7	22.9/10.7	22.9/10.7
XMTR ANT SIZE - FT	8	6	4	6	6	8	6	4
RCVR ANT SIZE - FT	8	10	15	15	6	10	8	12
NET ANTENNA GAIN-DB	77.17	76.61	76.61	80.13	72.17	79.11	74.67	74.67
FWD FEEDER LOSS -DB	5.80	5.80	5.80	5.80	5.80	5.80	5.80	5.80
RCVR NOISE FIG - DB	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0
IF BANDWIDTH - MHZ	25.00	25.00	25.00	25.00	25.00	25.00	25.00	25.00
RCVR THRESHOLD- DBM	-69.50	-69.50	-69.50	-69.50	-69.50	-69.50	-69.50	-69.50
FOR A BER OF	5.0E-09	5.0E-09	5.0E-09	5.0E-09	5.0E-09	5.0E-09	5.0E-09	5.0E-09
99.99 PER-CENT PATH LOSS -DB	160.71	160.71	160.71	160.71	160.71	160.71	160.71	160.71
RCVD PWR -DBM	-52.35	-52.91	-52.91	-56.38	-57.35	-57.40	-61.84	-61.84
99.90 PER-CENT PATH LOSS -DB	159.34	159.34	159.34	159.34	159.34	159.34	159.34	159.34
RCVD PWR -DBM	-50.98	-51.54	-51.54	-55.01	-55.98	-56.03	-60.47	-60.47
99.0 PER-CENT PATH LOSS -DB	157.69	157.69	157.69	157.69	157.69	157.69	157.69	157.69
RCVD PWR -DBM	-49.33	-49.89	-49.89	-53.36	-54.33	-54.38	-58.82	-58.82
95.0 PER-CENT PATH LOSS -DB	156.18	156.18	156.18	156.18	156.18	156.18	156.18	156.18
RCVD PWR -DBM	-47.82	-48.38	-48.38	-51.85	-52.82	-52.87	-57.31	-57.31
90.0 PER-CENT PATH LOSS -DB	155.40	155.40	155.40	155.40	155.40	155.40	155.40	155.40
RCVD PWR -DBM	-47.04	-47.60	-47.60	-51.07	-52.04	-52.09	-56.53	-56.53
50.0 PER-CENT PATH LOSS -DB	152.60	152.60	152.60	152.60	152.60	152.60	152.60	152.60
RCVD PWR -DBM	-44.24	-44.80	-44.80	-48.27	-49.24	-49.29	-53.73	-53.73
TIME AVAILABILITY:								
OBJECTIVE	99.9990	99.9990	99.9990	99.9990	99.9990	99.9990	99.9990	99.9990
PREDICTED	99.99927	99.99905	99.99905	99.99536	99.99278	99.99260	99.94477	99.94477
	DCA QUALITY			LESS THAN DCA QUALITY				

TABLE 10

SPECTRUM OCCUPANCY AT EMBASSY

NO.	FREQUENCY MHz	AZ DEG	EL DEG	POL	POWER DENSITY dBm/m^2	REGION OF POTENTIAL INTERFERENCE FOR COMMUNICATION FROM THE RECEIVER SITE MHz
1	4202.5	186	0	V	-73.5	None
2	4614.9	163	0	H	-71.7	None
3	4749.9	97	0	V	-63.5	None
4	4860.7	46	+1	H	-75.3	4840.9 - 4880.5
5	4869.7	122	0	V	-63.1	None
6	4887.0	176	0	V	-83.8	None

TABLE 11

SPECTRUM OCCUPANCY AT RECEIVER SITE

NO.	FREQUENCY MHz	AZ DEG	EL DEG	POL	POWER DENSITY dBm/m^2	REGION OF POTENTIAL INTERFERENCE FOR COMMUNICATION FROM THE: EMBASSY MHz	MAC TERMINAL MHz	TECHNICAL CONTROL MHz
1	4202.5	223	+1	V	-95.61	None	None	None
2	4470.0	198	0	V	-72.66	None	None	None
3	4499.0	208	0	H	-70.22	None	None	None
4	4557.4	204	0	V	-70.11	None	None	None
5	4590.0 to (1) 4591.2	204	0	V	-72.56	None	None	None
6	4614.9	204	0	H	-67.16	None	None	None
7	4636.2	180	+5	V	-76.87	None	None	None
8	4673.1	204	0	V	-70.49	None	None	None
9	4706.25	245.5	-2	H&V	-31.44	4680.9 - 4731.64	4677.8 - 4734.7	4656.7 - 4755.8
10	4720.4	195	+3	V	-86.41	None	None	None
11	4749.8	202	0	V	-74.24	None	None	None
12	4770.1	205	0	V	-62.79	None	None	None
13	4828.1	205	0	V	-54.58	4815.8 - 4840.4	None	None
14	4860.8	NA	NA	H&V	-30.11	4843.1 - 4878.5 4820.8 - 4900.8(2) 4988.3 - 5013.8(2)	4843.1 - 4878.5 4820.8 - 4900.8(2) 4988.3 - 5013.8(2)	4843.1 - 4878.5 4820.8 - 4900.8(2) 4988.3 - 5013.8(2)
15	4869.8	189	+1	V	-75.70	None	None	None
16	4886.1	206	0	H	-63.63	None	None	None
17	4943.8	207	0	V	-44.29	4924.2 - 4963.4	4927.7 - 4959.9	None

(1) - Indicates a Sweeping Frequency Between the Limits Stated.
(2) - As per MIL-STD-188-313 for a Receiver Colocated with a Transmitter.

TABLE 12

SPECTRUM OCCUPANCY AT TECHNICAL CONTROL

NO.	FREQUENCY	AZ	EL	POL	POWER DENSITY	REGION OF POTENTIAL INTERFERENCE FOR COMMUNICATION FROM THE:	
						RECEIVER SITE	MAC TERMINAL
	MHz	DEG	DEG		dBm/m^2	MHz	MHz
1	4205.5	255	+1	H	-79.08	None	None
2	4470.2	181	-4	V	-70.31	None	None
3	4498.9	186	0	H	-66.04	None	None
4	4557.4	184	-1	V	-71.65	None	None
5	4590.2 To (1) 4591.3	183	-2	V	-67.01	None	None
6	4614.9	185	-3	H	-66.26	None	None
7	4673.1	188	-3	V	-71.35	None	None
8	4706.25	NA	NA	H&V	-32.13	4690.1 - 4722.4 4666.25 - 4746.25 (2) 4833.75 - 4858.75 (2)	4690.1 - 4722.4 4666.25 - 4746.25 (2) 4833.75 - 4858.75 (2)
9	4749.8	195	-2	V	-70.55	None	None
10	4770.3	203	-3	H	-65.94	None	None
11	4828.6	203	0	V	-77.56	None	None
12	4860.8	65.5	+2	H&V	-36.19	4822.0 - 4899.6	4846.0 - 4875.6
13	4869.4	194	-4	V	-76.69	None	None
14	4885.7	189	-2	H	-70.49	None	None
15	4943.9	207	-3	V	-68.03	None	None

(1) - Indicates a Sweeping Frequency Between the Limits Stated.
(2) - As Per MIL-STD-188-313 for a Receiver Colocated with a Transmitter.

TABLE 13

SPECTRUM OCCUPANCY AT MAC TERMINAL

NO.	FREQUENCY MHz	AZ DEG	EL DEG	POL	POWER DENSITY dBm/m^2	REGION OF POTENTIAL INTERFERENCE FOR COMMUNICATION FROM THE: TECHNICAL CONTROL MHz	RECEIVER SITE MHz
1	4202.1	101	0	V	-79.62	None	None
2	4299.3	260	0	V	-41.37	None	None
3	4434.5	285	0	V	-61.78	None	None
4	4470.0	100	0	V	-70.43	None	None
5	4499.0	100	0	H	-83.03	None	None
6	4557.1	90	0	V	-80.59	None	None
7	4590.2	95	0	V	-69.21	None	None
8	4614.9	95	-1	H	-81.71	None	None
9	4673.2	120	0	V	-85.38	None	None
10	4705.2	60	0	H&V	-83.75	None	None
11	4750.0	100	0	V	-65.54	None	None
12	4828.3	190	0	V	-66.41	None	None
13	4860.7	60	0	H	-61.29	4841.6 - 4879.8	4837.4 - 4884.1
14	4869.6	100	0	V	-75.23	None	None
15	4886.0	190	-2	H	-70.51	None	None
16	4943.8	190	0	V	-74.99	None	None

TABLE 14

RECOMMENDED LINK DESIGN FOR DCA QUALITY

1. Embassy to Receiver Site

   a. 1 watt frequency diversity AN/FRC-155(V) radios
   b. 92 FT = antenna height at Embassy
   c. 4 FT = dish size at Embassy
   d. 50 FT = antenna height at Receiver Site
   e. 6 FT = dish size at Receiver Site

2. Technical Control to Receiver Site

   a. 1 watt frequency diversity AN/FRC-155(V) radios
   b. 100 FT = antenna height at Technical Control
   c. 43 FT = antenna height at Receiver Site
   d. 4 FT dish at each end of the link

3. Mac Terminal to Receiver Site

   a. 5 watt frequency diversity AN/FRC-157(V) radios
   b. 75 FT = antenna height at Mac Terminal
   c. 35 FT = antenna height at Receiver Site
   d. 8/8, 6/10, or 4/15 dishes

TABLE 15

TAP MICROWAVE LINK FREQUENCY PLAN

LINK	TRANSMIT FREQUENCIES, MHz	POLARIZATION	NOTE
Embassy to Receiver Site	4510, 4795	H	1, 2
Receiver Site to Embassy	4670, 4985	H	1, 2
Mac Terminal to Receiver Site	4410, 4720	V	1, 2, 3
Receiver Site to Mac Terminal	4625, 4880	V	1, 2, 3
Technical Control to Receiver Site	4460, 4760	H	1, 2
Receiver Site to Technical Control	4570, 4920	H	1, 2

NOTES:

1. All links use frequency diversity.
2. Shrouded antennas are required at Receiver Site.
3. Existing link from Technical Control to Receiver Site must be deactivated before this link is activated.

APPENDIX A. PATH LOSS MEASUREMENTS AND ANALYSIS

A.1 OBJECTIVES

A.1.1 Measurement Objectives. The measurement objectives were to determine the path loss and optimum positions on the existing towers for the proposed microwave antennas. This involved determining what height on each existing tower would provide good unobstructed line-of-sight propagation (free space path loss). However, the two routes to the Mac Terminal were obstructed at all heights on the existing towers.

A.1.2 Analysis Objectives. Using the measured data, the analysis objectives were to determine the optimum antenna size and expected link performance using the 1 watt AN/FRC-155(V) or the 5 watt AN/FRC-157(V) radios (see Table 1).

A.2 MEASUREMENT SYSTEM. Table 16 shows the major items of equipment and their characteristics, and Figures 7 and 8 show the diagrams of the measurement system configurations used. In addition, ancillary equipment such as antenna tripods with pan and tilt heads, RF connectors, adapters, cables, frequency counter, step attenuator, spectrum analyzer, and a power meter were used to complete the measurement system. All instrumentation requiring calibration was certified at the "A" level by the Standards and Calibration Laboratory, US Army Electronic Proving Ground, Fort Huachuca, Arizona, prior to the survey.

A.3 MEASUREMENT PROCEDURE

A.3.1 Antenna Heights. For each of the four links tested, the transmit antenna was mounted at a fixed height (near the top of the tower) and, at the opposite end of each link, the receive antenna was varied in height. Section 3 provides the specific heights used for each link. Only existing towers were used in the tests.

A.3.2 Frequencies. A CW signal at 4700 or 4720 MHz was selected so as to avoid interference with the existing link from the Technical Control to the Receiver Site. These test frequencies are in the middle of the 4.4-5.0 GHz frequency band and are considered representative of the entire band.

A.3.3 Recording Periods. At each antenna height, path loss measurements were taken for a minimum of 2 hours and in some cases up to 19 hours when overnight recordings were feasible. This relatively short recording period was considered acceptable on the line-of-sight paths because signal strengths did not vary significantly with time due to the short path lengths involved. On the two obstructed (diffraction) paths to the Mac Terminal, longer recording periods would have been desirable.

A.3.4 Equipment Checks. Periodically, the transmitter power into the transmitting antenna and the receiving system gain and sensitivity were checked. The transmitter power was normally 30 dBm (1 watt) and the receiving system sensitivity was typically -115 dBm for a 500 KHz bandwidth.

A.4 ANALYSIS

A.4.1 Data Reduction Procedure. Hourly median received signal strength was determined from the strip chart recordings. Hourly median path loss was then determined from the following formula:

$$Lp = Pt - Pr + Gt + Gr + Gs \text{ in dB}$$

where:

Lp = hourly median path loss in dB

Pt = transmitter power (dBm) into the transmit antenna

Pr = hourly median received signal level in dBm

Gt = gain of the transmit antenna in dBi

Gr = gain of the receive antenna in dBi

Gs = net gain of the receiving system in dB

The amount of obstruction loss was determined as follows:

$$ACR = Lp - L_{fs}$$

where:

ACR = attenuation relative to free space = obstruction loss in dB

Lp = as defined above

L_{fs} = free space path loss

$$= 32.45 + 20 \text{ LOG } (F) + 20 \text{ LOG } (D) \text{ in dB}$$

where:

F = frequency in MHz

D = path length in km

The reduced data for each link is provided in Section 3, Figures 2 thru 6 and Tables 2, 4, 6, and 8. Sample strip chart recordings are shown in Appendix B.

A.4.2 Performance Analysis.

a. The performance analysis was accomplished using this Agency's computerized prediction model called "CANDID". CANDID, which stands for Combined Analog and Digital Deck, will analyze the RF portion of any VHF, UHF, SHF, analog, quasi-analog, digital, line-of-sight, diffraction, or tropospheric scatter communication link. CANDID actually consists of several computerized prediction models combined into one large model. All of the hourly median path loss prediction models were developed and published by the Institute for Telecommunication Sciences, Office of Telecommunications, Department of Commerce, 325 Broadway, Boulder, Colorado 80302 (references 8, 9, and 10). The remainder of the model, including system performance and reliability predictions, was developed internally by the Electromagnetic Engineering Office (EMEO) of this Agency. CANDID is based upon references 7 through 15.

b. The analysis was performed by inserting the measured obstruction loss into CANDID and using the various simulation models to predict the expected performance. Time availability (propagation reliability) is calculated by superimposing a short term rapid fading simulation model on the long term hourly median path loss model. The outage time for each hour of bad propagation is calculated and summed to obtain the total cumulative annual outage time and reliability. Tables 3, 5, 7, and 9, in Section 3, show the condensed summary output from CANDID for the four links.

TABLE 16

LIST OF MAJOR EQUIPMENT - PATH LOSS MEASUREMENTS

ITEM	CHARACTERISTICS
TRANSMIT	
a. Hewlett-Packard Sweep Oscillator consisting of an HP-8620C Mainframe and an HP-86290A RF Plug-in.	2-18 GHz frequency range. 4700 & 4720 MHz = CW frequencies used.
b. Hewlett-Packard Power Amplifier, Model HP-493A.	1 watt output power. 4-8 GHz frequency range.
RECEIVE	
a. Watkins-Johnson Solid State Low Noise Preamp, Model WJ-5300-89.	4-8 GHz frequency range. 45 dB gain. 3.0 dB noise figure.
b. Singer Field Intensity Meter, Model NM-65T.	1.0-10.0 GHz frequency range. 27-36 dB noise figure for 4.4-10.0 GHz.
ANTENNAS	
Two 18 inch Parabolic Dishes with horn feeds.	23.8 dB gain from 4.2-5 GHz. 9.9 degrees = Half power beamwidth.

FIGURE 7

TRANSMITTER CONFIGURATION

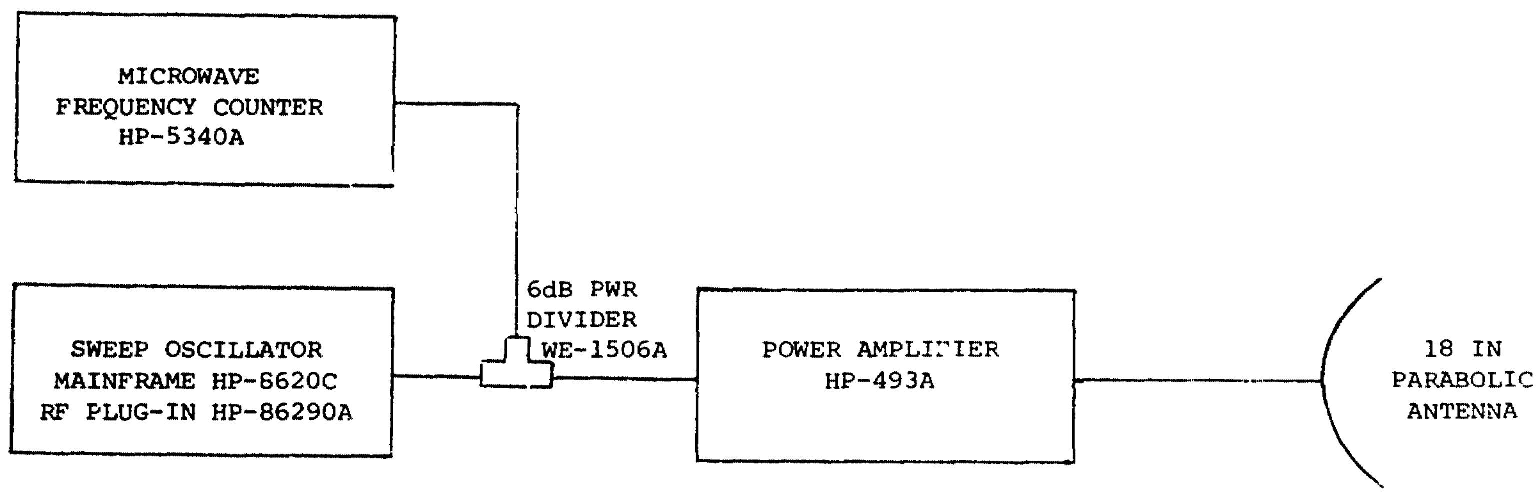
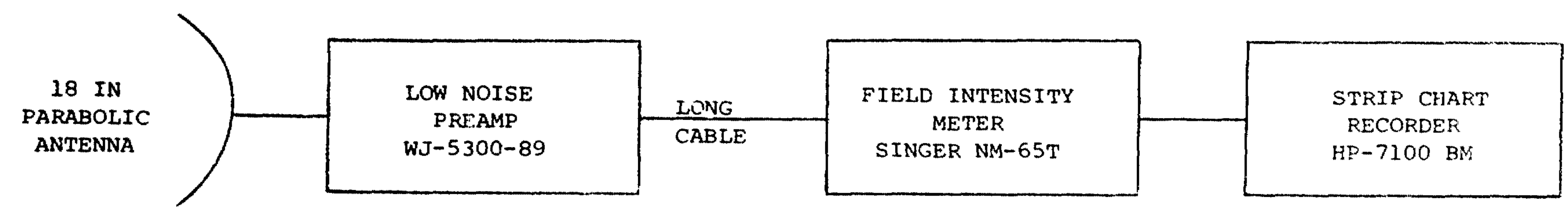


FIGURE 8

RECEIVER CONFIGURATION



APPENDIX B. SAMPLE PATH LOSS MEASUREMENTS

Figures 9-11 show sample path loss measurements. The strip chart recordings of received signal level have been converted to path loss.

Figure 9 shows a sample path loss measurement over the Embassy to Receiver Site link where normal line-of-sight propagation was observed.

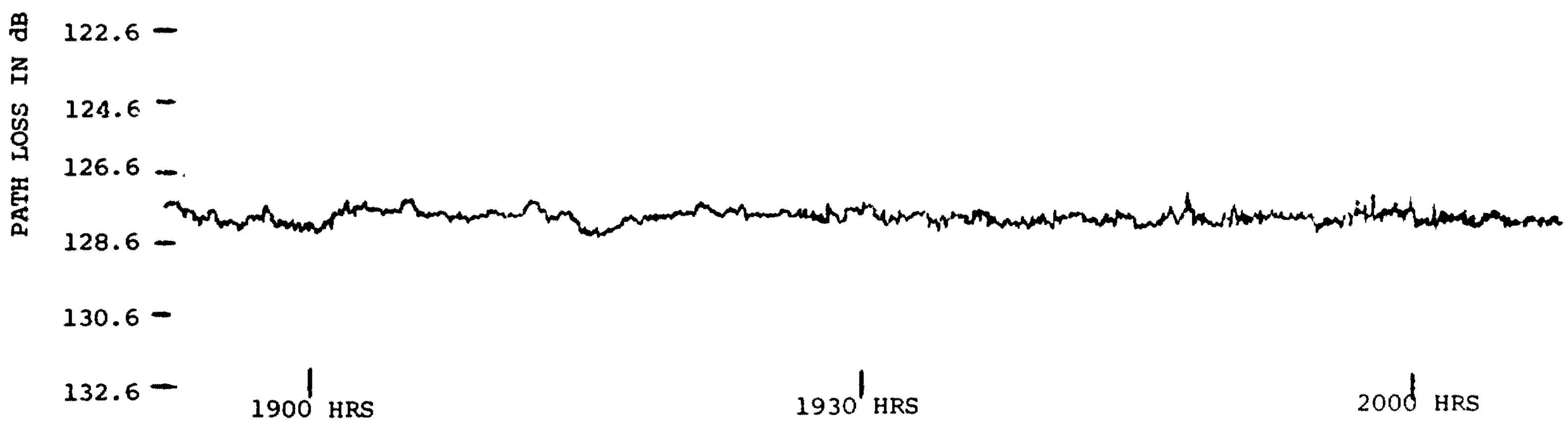
Figure 10 shows the effect of a large metal hydraulic construction crane swinging I-beams back and forth across the Embassy to Receiver Site link. Fortunately, the new building under construction is slightly off path and is not expected to obstruct this link. Heavy construction of this nature is going on continually in the greater Tehran area. For this reason a sizable safety margin is incorporated into the recommended design of this link. The crane completed its job in 3 days and normal measurements were able to continue. During this same time period the Embassy's existing 900 MHz communications on the same tower were affected and the EMC team explained that it was the crane and not the men on the tower that caused the problem.

Figure 11 shows the effect of wind and dust on the Mac Terminal to Receiver Site link. The dust storm did not last very long but was severe enough to cause the deep fades shown on Figure 11. The break in the strip chart recording was caused by the engineer switching the received signal to a spectrum analyzer for a brief period.

FIGURE 9

SAMPLE PATH LOSS MEASUREMENT - EMBASSY TO RECEIVER SITE

4720 MHz, VERTICAL POLARITY
12.60 Km = PATH LENGTH
68.5 FT = ANTENNA HEIGHT AT EMBASSY
40.5 FT = ANTENNA HEIGHT AT RECEIVER SITE

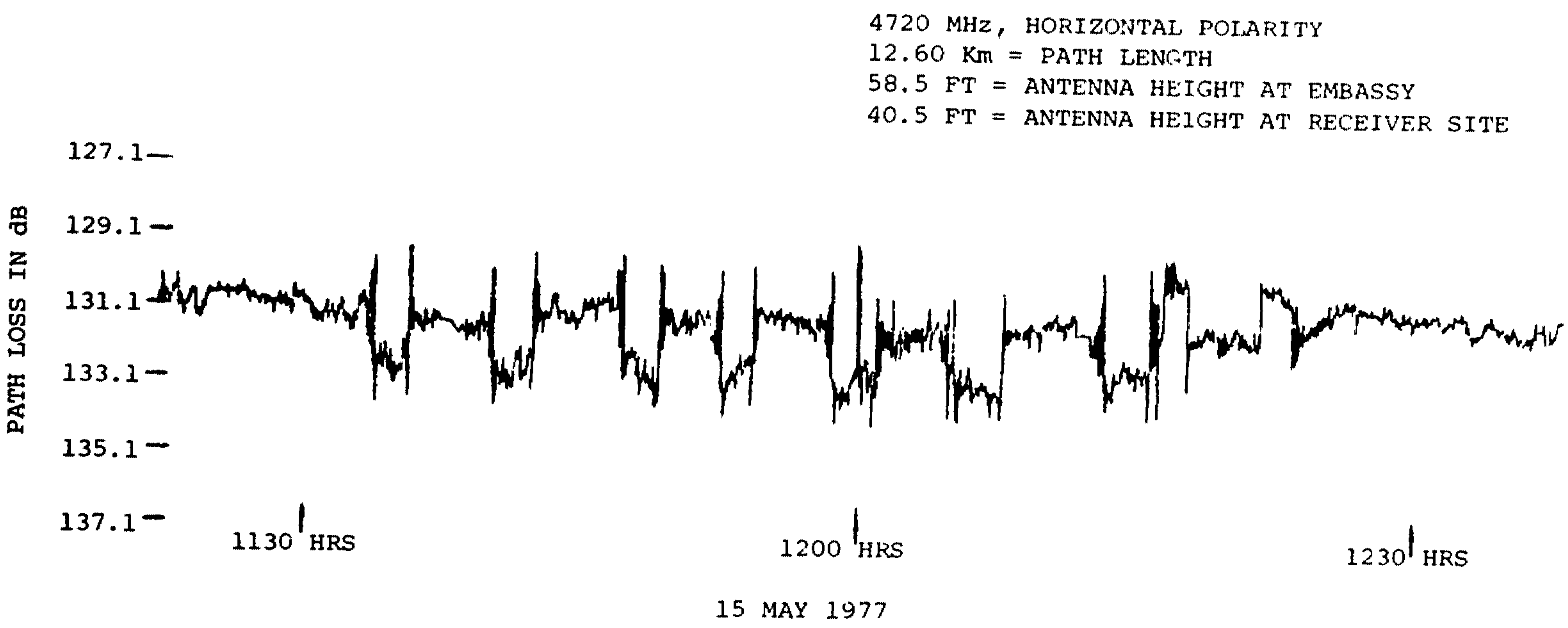


17 MAY 1977

NORMAL LINE-OF-SIGHT PROPAGATION

FIGURE 10

SAMPLE PATH LOSS MEASUREMENT - EMBASSY TO RECEIVER SITE

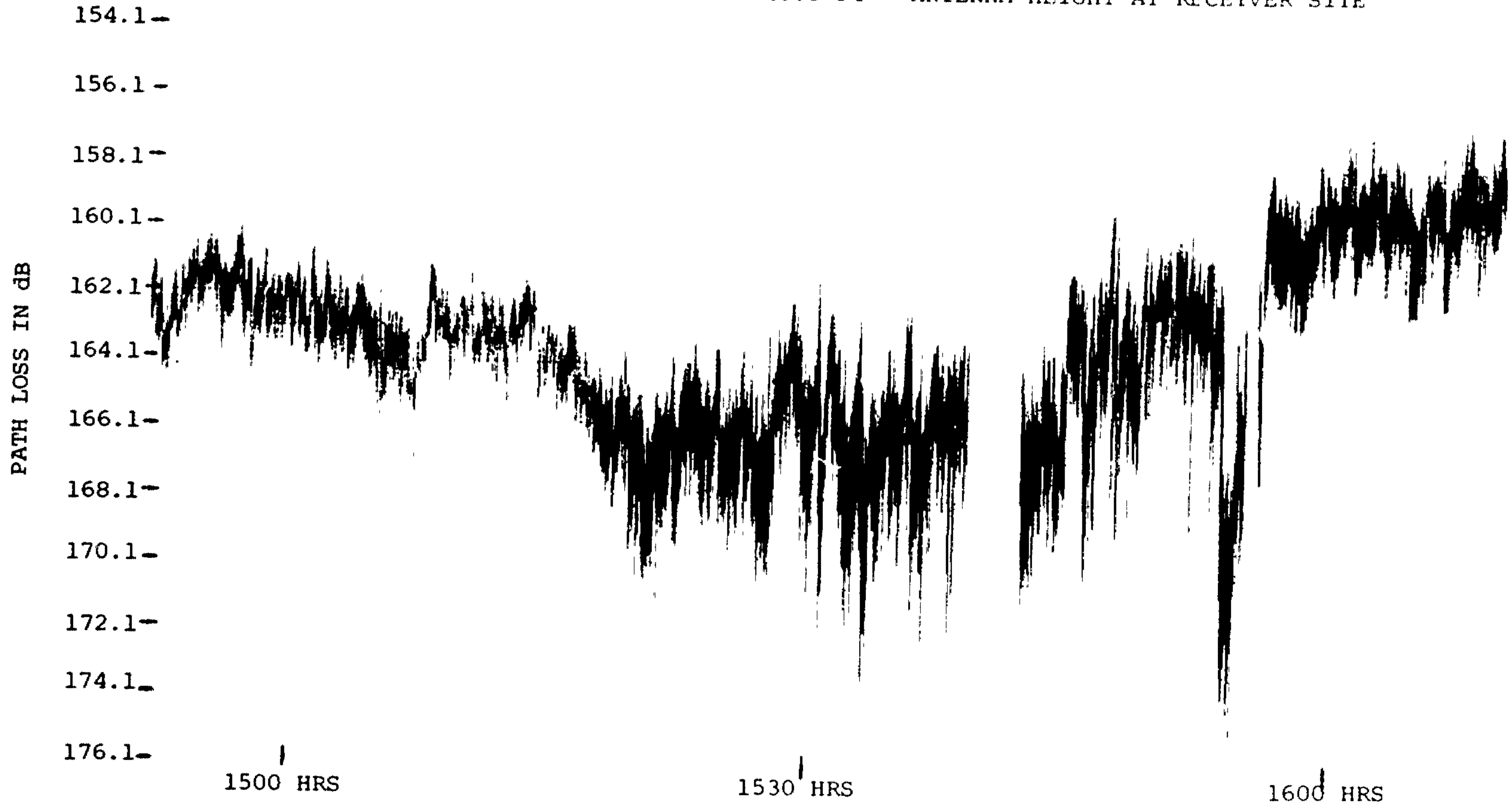


The Effects of a Large Metal Hydraulic Construction Crane Swinging I-Beams Back and Forth.

FIGURE 11

SAMPLE PATH LOSS MEASUREMENT - MAC TERMINAL TO RECEIVER SITE

4720 MHz, VERTICAL POLARITY
20.57 Km = PATH LENGTH
56.5 FT = ANTENNA HEIGHT AT MAC TERMINAL
40.5 FT = ANTENNA HEIGHT AT RECEIVER SITE



5 JUNE 1977

THE EFFECTS OF WIND AND DUST

APPENDIX C. SPECTRUM OCCUPANCY MEASUREMENTS AND ANALYSIS

C.1 OBJECTIVES. The objective of the spectrum occupancy measurements was to determine the significant signals present at each site and to document their strength (power density), polarity, azimuth and elevation arrival angles. The objective of the analysis was to determine which of the documented signals were strong enough to be potential interferers with the proposed TAP microwave links. Regions of potential interference were calculated and a frequency plan is provided. The overall objective of the measurements and analysis was to increase the probability of the proposed TAP microwave links being electromagnetically compatible with the environment.

C.2 MEASUREMENT SYSTEM. Table 17 shows the major items of equipment and their characteristics, and Figure 12 shows the diagram of the measurement system. In addition, ancillary equipment such as an antenna tripod with pan and tilt head, RF connectors, adapters, cables, step attenuator, and scope camera were used to complete the measurement system. All instrumentation requiring calibration was certified at the "A" level by the Standards and Calibration Laboratory, US Army Electronic Proving Ground, Fort Huachuca, Arizona, prior to the survey. The frequency range covered in the measurements was 4.2-5.0 GHz, which includes the required frequency band of 4.4-5.0 GHz plus the image band.

C.3 MEASUREMENT PROCEDURE

C.3.1 Antennas. At each site, the measurement system antenna was mounted at the top of the existing tower. The 18 inch dish was used for measurement of all but the colocated transmitters at the Technical Control and Receiver Site. The measurement of the colocated transmitters was performed with the conical log spiral antenna to permit far field measurements to be taken.

C.3.2 Measurement Routine. The measurement routine consisted of two phases. First, a cursory 360° scan of the horizon was made to detect all incoming signals. In the second phase, all signals were pinpointed and documented in terms of arrival azimuth, elevation angle, polarization, amplitude and frequency. CRT photographs of each signal were taken. Precision frequency determination was accomplished by signal substitution using the sweep oscillator and frequency counter shown in Figure 12.

C.3.3 Equipment Checks. The measurement system net gain and sensitivity were determined daily. The sensitivity was normally -115 to -120 dBm (depending on cable lengths) for a 100 KHz spectrum analyzer bandwidth.

C.4 ANALYSIS

C.4.1 Data Reduction Procedure.

a. Spectral characterization of each signal consisted of the center frequency, power spectral density and power flux density. The power flux

density was obtained by approximating;

$$P = 10 \log \int_{f_1}^{f_2} p(f)\,df - G_m - A_m \qquad \text{Equation 1}$$

where:

P = power flux density (dBm/m^2) of a signal

$p(f)$ = power spectral density (mW/Hz)

G_m = measurement system net gain (dB)

A_m = measurement antenna effective area (dBm^2)

by: $$P = 10 \log \sum_{i=1}^{n} [10^{P_i/10} - N] - G_m - A_m \qquad \text{Equation 2}$$

where: P_i = amplitude (dBm/BW_m) of the received signal plus noise at frequency f_i

N = average noise level of the measurement receiver (mW)

and: BW_m = bandwidth of the measurement receiver

b. Each signal was also identified by the following:

(1) Polarization of maximum amplitude

(2) Arrival azimuth of maximum amplitude

(3) Arrival elevation of maximum amplitude

The reduced data is provided in Section 3, Tables 10-13. A sample photograph of a signal received is provided in Appendix D.

C.4.2 Interference Criterion. The interference criterion used is an interference-to-noise ratio of 0 dB as per reference 7. Table 18 shows the interference threshold and filter characteristics of the proposed AN/FRC-155(V) and AN/FRC-157(V) radios.

C.4.3 Interference Analysis.

a. Potential interference was determined from the following:

$$I = 10 \log \sum_{i=1}^{n} [(10^{Pi/10} - N)/OTR_i] - G_m - A_m + A_t \qquad \text{Equation 3}$$

where:

I = predicted effective signal power (dBm) of a detected signal at the output of the receive terminal antenna feed.

A_t = effective area of the receive terminal antenna in the direction of the detected signal (dBm^2).

(A_t obtained from gain patterns described in Reference 16.)

P_i, G_m, A_m and N were previously defined.

OTR_i = rejection due to bandwidth mismatch.

$$OTR_i = [1+(2|f_0-f_i|/BW_1)^{2N_1}] \times [1+(2|f_0-f_i|/BW_2)^{2N_2}] \quad \text{Equation 4}$$

f_0 = RF frequency corresponding to the center of the IF band pass = center of received signal

f_i = RF frequency of P_i

BW_1 = 3 dB bandwidth of the RF Butterworth filter

N_1 = Number of poles of the RF Butterworth filter

BW_2 = 3 dB bandwidth of the IF Butterworth filter

N_2 = Number of poles of the IF Butterworth filter

b. Whenever I exceeds IT, a possible interference condition exists and guard bands required to avoid possible interference were determined by the following method:

$$IT \geq 10 \log \sum_{i=1}^{n} [(10^{P_i/10} - N)/OFR_i] - G_m - A_m + A_t \quad \text{Equation 5}$$

where:

IT = interference threshold (defined in Table 18) in dBm

OFR_i is defined as in Equation 4, except that f_0 is varied so that the inequality of Equation 5 becomes satisfied. All other parameters are as previously defined.

The results of the interference analysis is provided in Section 3, Tables 10-13.

TABLE 17

LIST OF MAJOR EQUIPMENT - SPECTRUM OCCUPANCY MEASUREMENTS

ITEM	CHARACTERISTICS
BASIC RECEIVER Hewlet-Packard Spectrum Analyzer consisting of Model 141T Variable Persistence Display Section, Model 8552B IF Section, Model 8555A RF Section and Model 8445B Preselector	10 MHz - 40 GHz frequency range. 39 dB noise figure.
AMPLIFICATION Watkins-Johnson Solid State Amplifier Model WJ-5300-89	4-8 GHz frequency range. 45 dB gain. 3.0 dB noise figure.
ANTENNAS a. 18 Inch Parabolic Dish With Feed Horn b. Conical Log Spiral	23.8 dB gain from 4.2-5.0 GHz. 9.9 degrees = Half power beamwidth. 5 dB gain from 4.2-5.0 GHz. ≈90 degrees = Half power beamwidth.

FIGURE 12

SPECTRUM OCCUPANCY MEASUREMENT CONFIGURATION

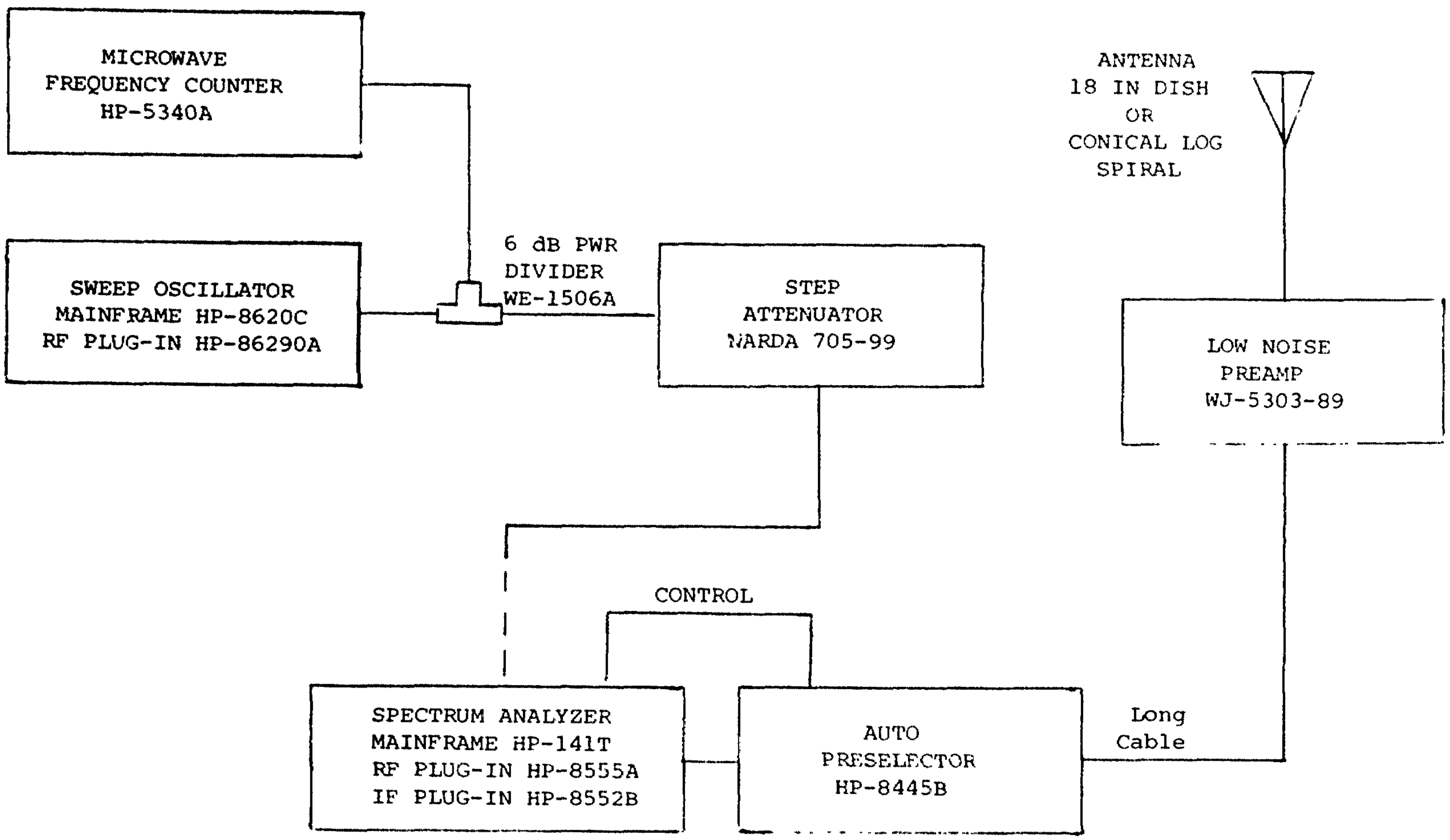


TABLE 18

Receiver Interference Threshold and Filter Characteristics
For AN/FRC-155(V) and AN/FRC-157(V) Radios

INTERFERENCE THRESHOLD (IT)	RF FILTER			IF FILTER		
	3dB BANDWIDTH	NO. OF POLES	MAXIMUM REJECTION	3dB BANDWIDTH	NO. OF POLES	MAXIMUM REJECTION
dBm	MHz		dB	MHz		dB
-90	50	7	120	25	4	38

NOTE:

1. All filters are assumed to be Butterworth.

2. IT = Interference threshold at the output of the receiving antenna.

   = 10 Log (KTB) + F in dBW

   = 10 Log (KTB) + F + 30 in dBm

   where: K = Boltzman's constant = 1.38×10^{-23} Joules/^{o}K

   T = noise temperature = 290^{o}K

   B = 3 dB IF bandwidth = 25×10^{6} Hertz

   F = effective system noise figure = 10 dB

3. The image band rejection of the AN/FRC-155(V) and AN/FRC-157(V) radios is 130 dB. Therefore, the interference threshold at image frequencies is + 40 dBm.

APPENDIX D. SPECTRUM OCCUPANCY MEASUREMENTS - SAMPLE PHOTOGRAPH

Figure 13 shows a sample photograph of a signal received at the Technical Control.

FIGURE 13

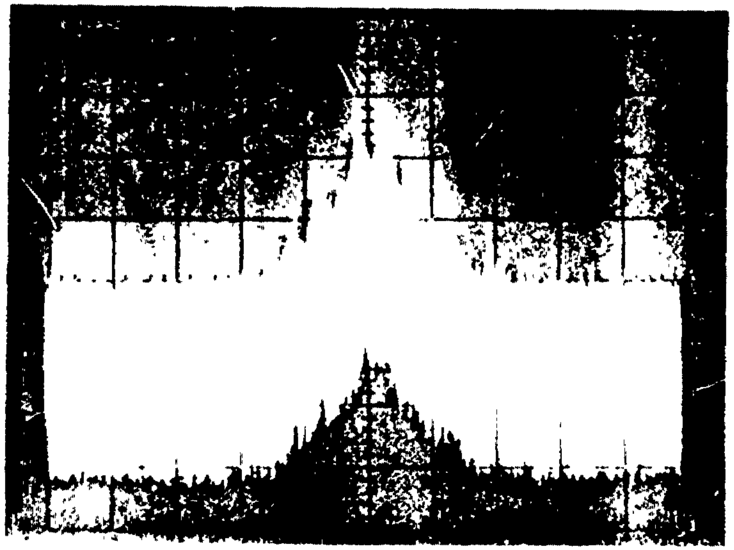
SPECTRUM ANALYZER
EMC PHOTO DATA SHEET

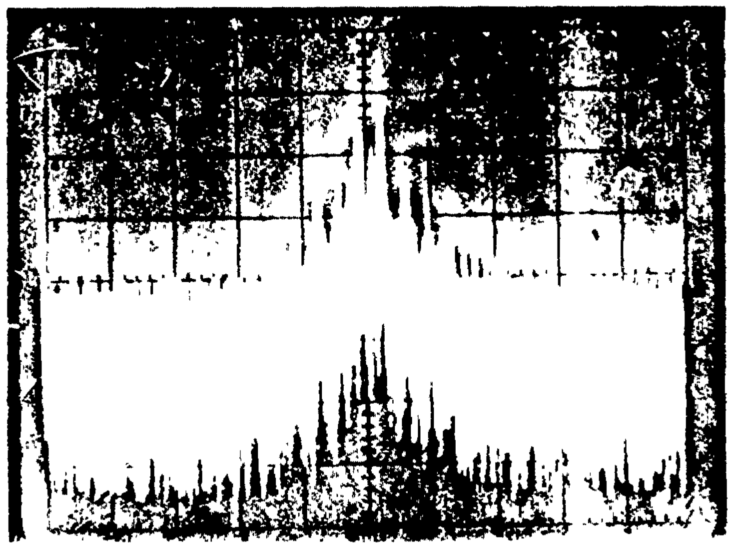
SITE TECHNICAL CONTROL

DATE 9 Jun 77

Time	1 2 3 ϕ
Bandwidth	1 ϕ ϕ kHz
Input Attenuator	1 ϕ dB
Scantime	50 M Sec/div
Mode	10 (circled), 2, L
Center Frequency	4498.9 MHz
Azimuth	18 6°
Elevation	ϕ°
Polarity	H (circled), V, 45
(Azimuth/Elevation/Polarity)	n/a
Instrumentation	
Scanwidth	.5 M Hz/div
Video Filter	0 (circled), 10k, 100, 10
Log Ref	-4ϕ dBm V/div
CABLES A	
CABLES B	
CABLES C	
CABLES D	
CABLES E	
External Attenuator	dB
Remarks	

Time	1 2 3 5
Bandwidth	1 ϕ kHz
Input Attenuator	1 ϕ dB
Scantime	5ϕM Sec/div
Mode	10 (circled), 2, L
Center Frequency	4498.9 MHz
Azimuth	18 6°
Elevation	ϕ°
Polarity	H (circled), V, 45
(Azimuth/Elevation/Polarity)	n/a
Instrumentation	
Scanwidth	.5 M Hz/div
Video Filter	0 (circled), 10k, 100, 10
Log Ref	-50 dBm V/div
CABLES A	
CABLES B	
CABLES C	
CABLES D	
CABLES E	
External Attenuator	dB
Remarks	





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